CC Coherent and CC neutral pion production results from MINERvA

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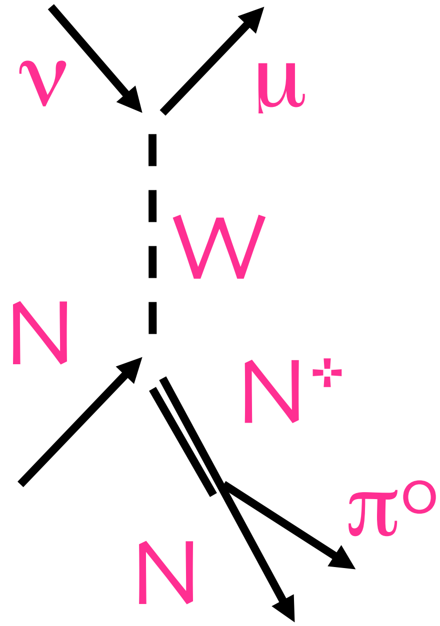
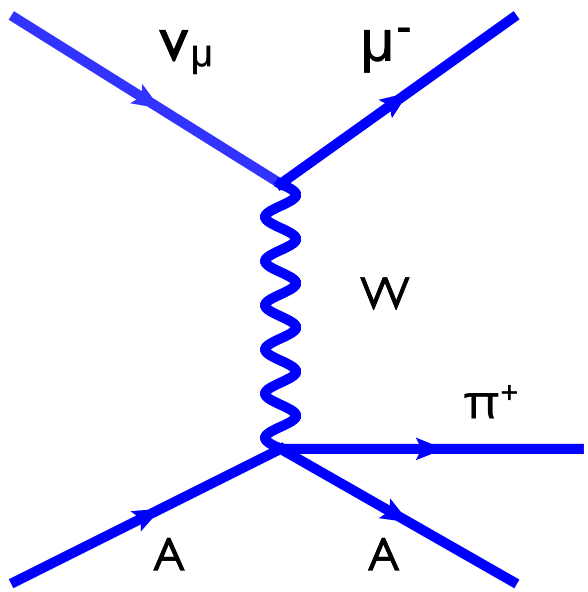
*Supported by University of Pittsburgh

Outline of Talk

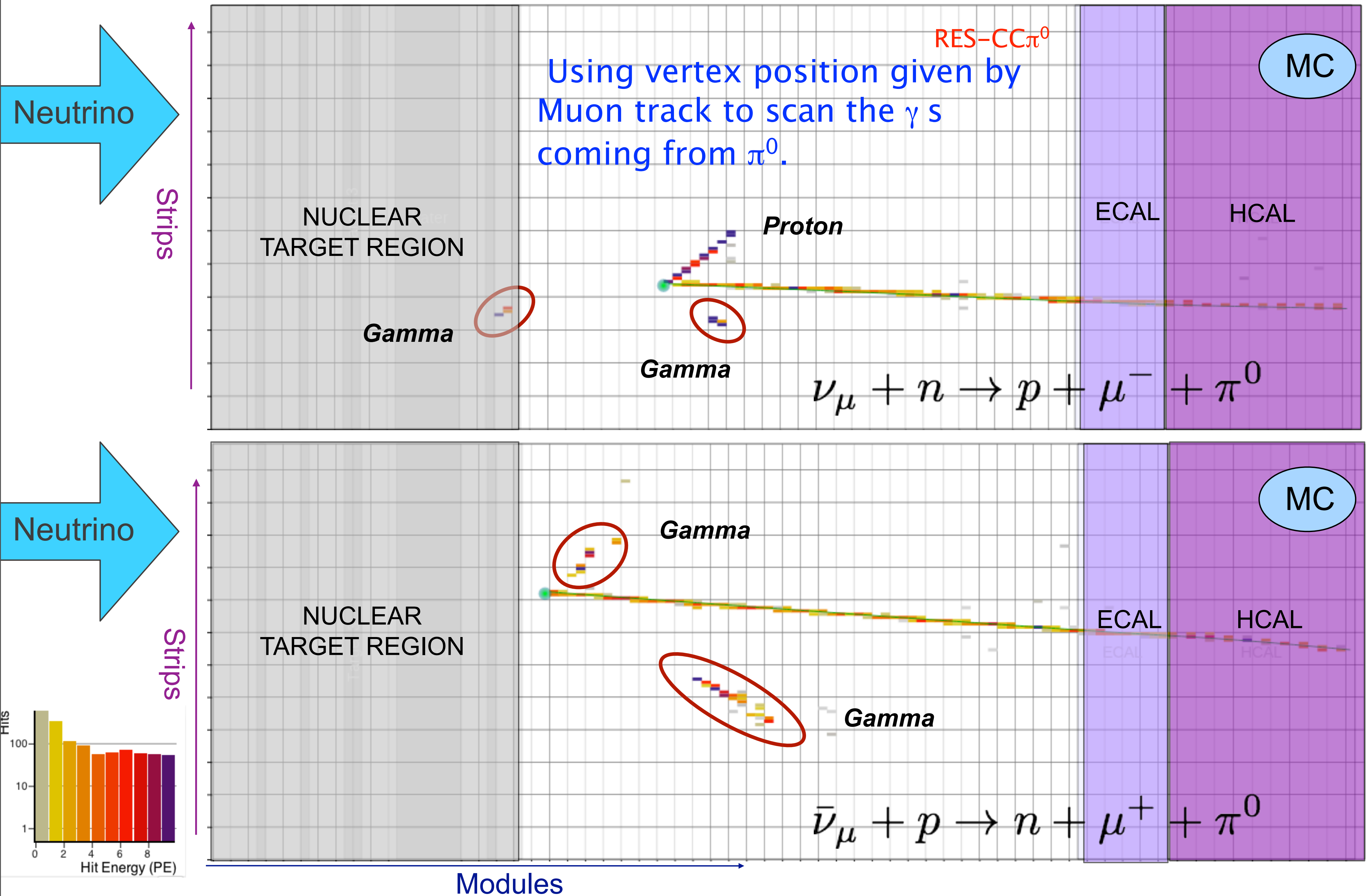
- CCπ^0 inclusive and exclusive reconstruction.



- CCπ^+ coherent production.



$CC\pi^0$ Event Topology



CCπ^0 reconstruction Data - MC

Event Selection for Anti neutrino interactions:

1 muon track with Minos Match(select anti-muons)

Hits to be reconstructed, must be inside 25ns respect to Vertex time.

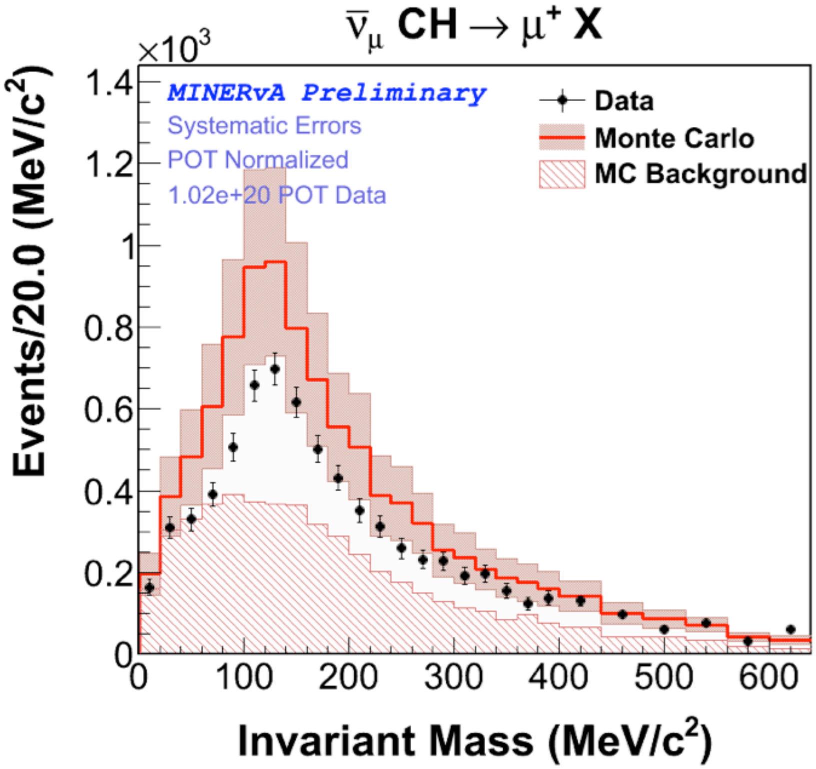
Muon vertex must be inside fiducial volume.

Showers must be reconstructed by Hough Transform (Energetic showers) or Angle Scan (low energy showers)

2 EM showers (shower vertex should be not close to muon vertex)

Energy in Nuclear Target Region < 20 MeV

Invariant Mass



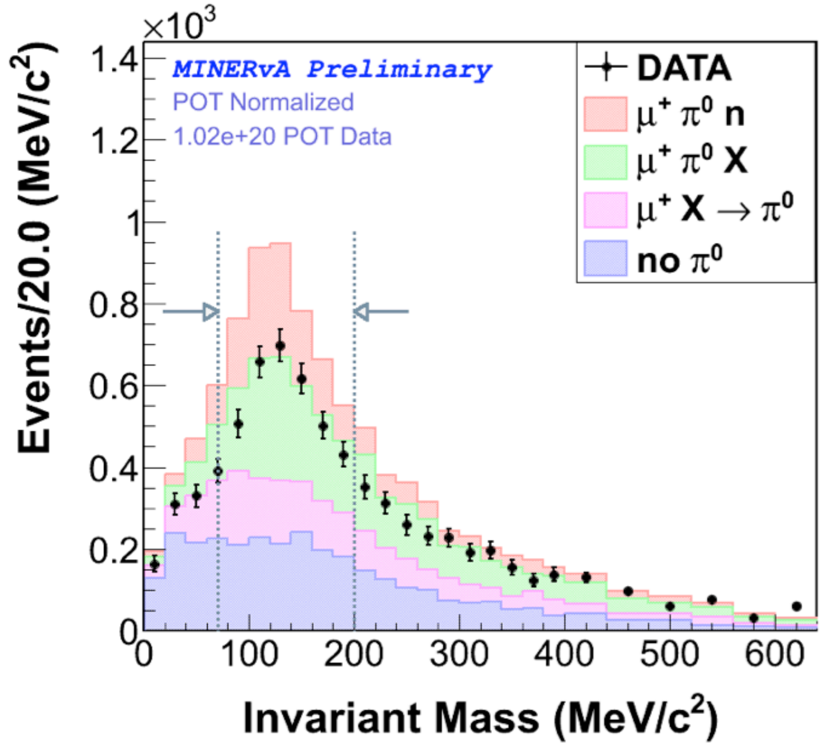
Cuts:

1 muon track + 2 EM showers

+ Energy in Target Region< 20 MeV

$$m_{\gamma\gamma} = \sqrt{2E_{\gamma_1} E_{\gamma_2} (1 - \cos\theta_{\gamma\gamma})}.$$

Background events could be Pion charge exchange in detector and wrong reconstruction.

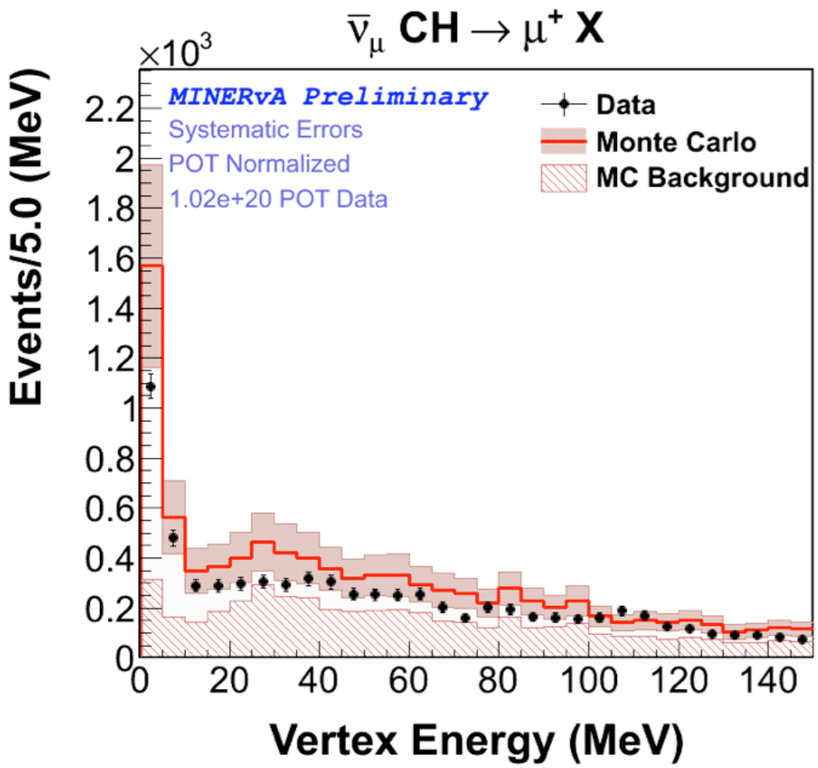


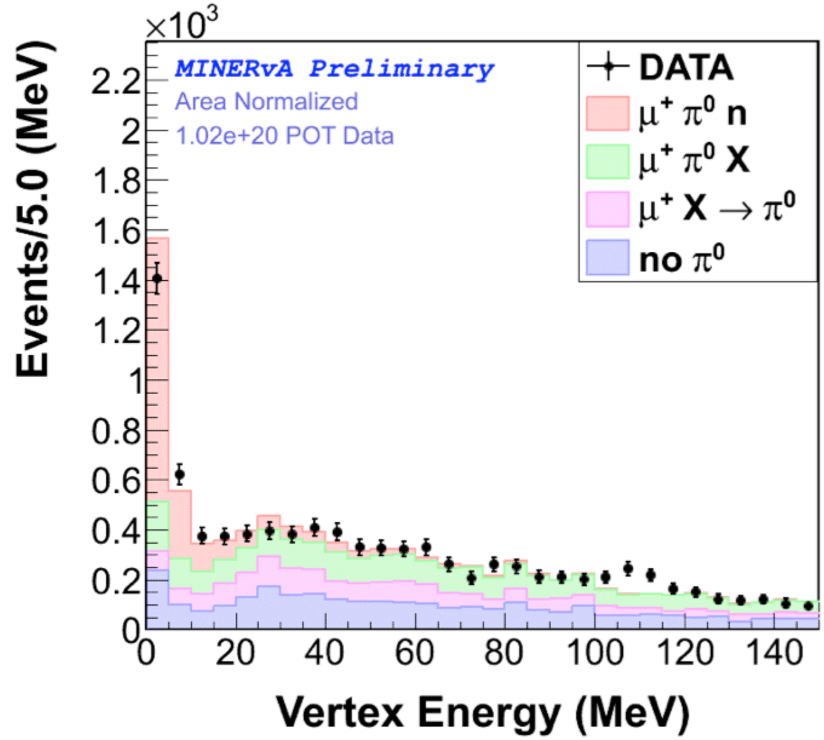
To reconstruct CCPi0 inclusive events, we will select events in certain mass range (70 - 200 MeV/c2).

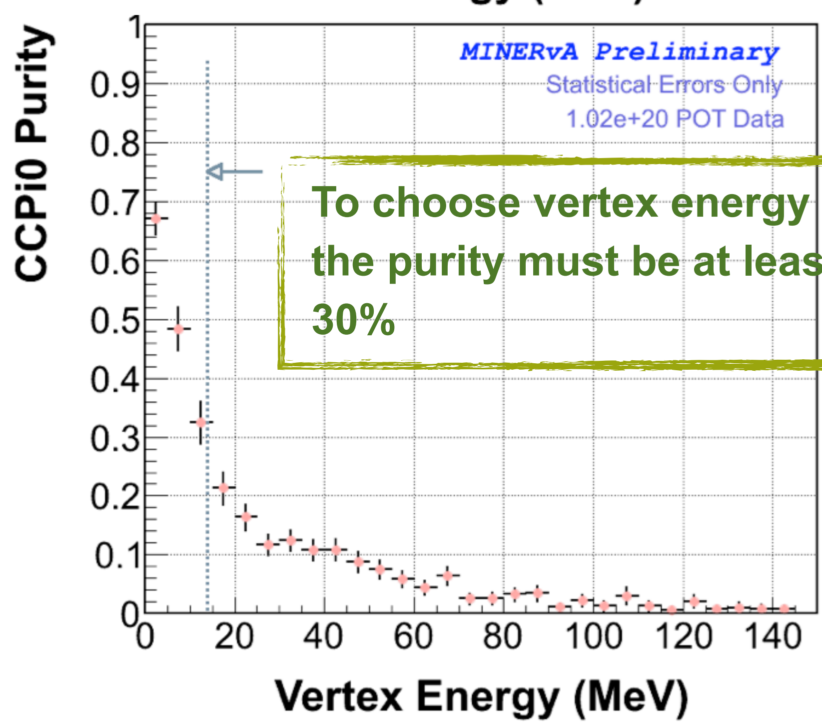
	$CC\pi^0$ inclusive
Purity	(54%)
Efficiency	(4.2%)

Vertex Energy

Vertex Activity:
Energy contained inside R = 90*mm*



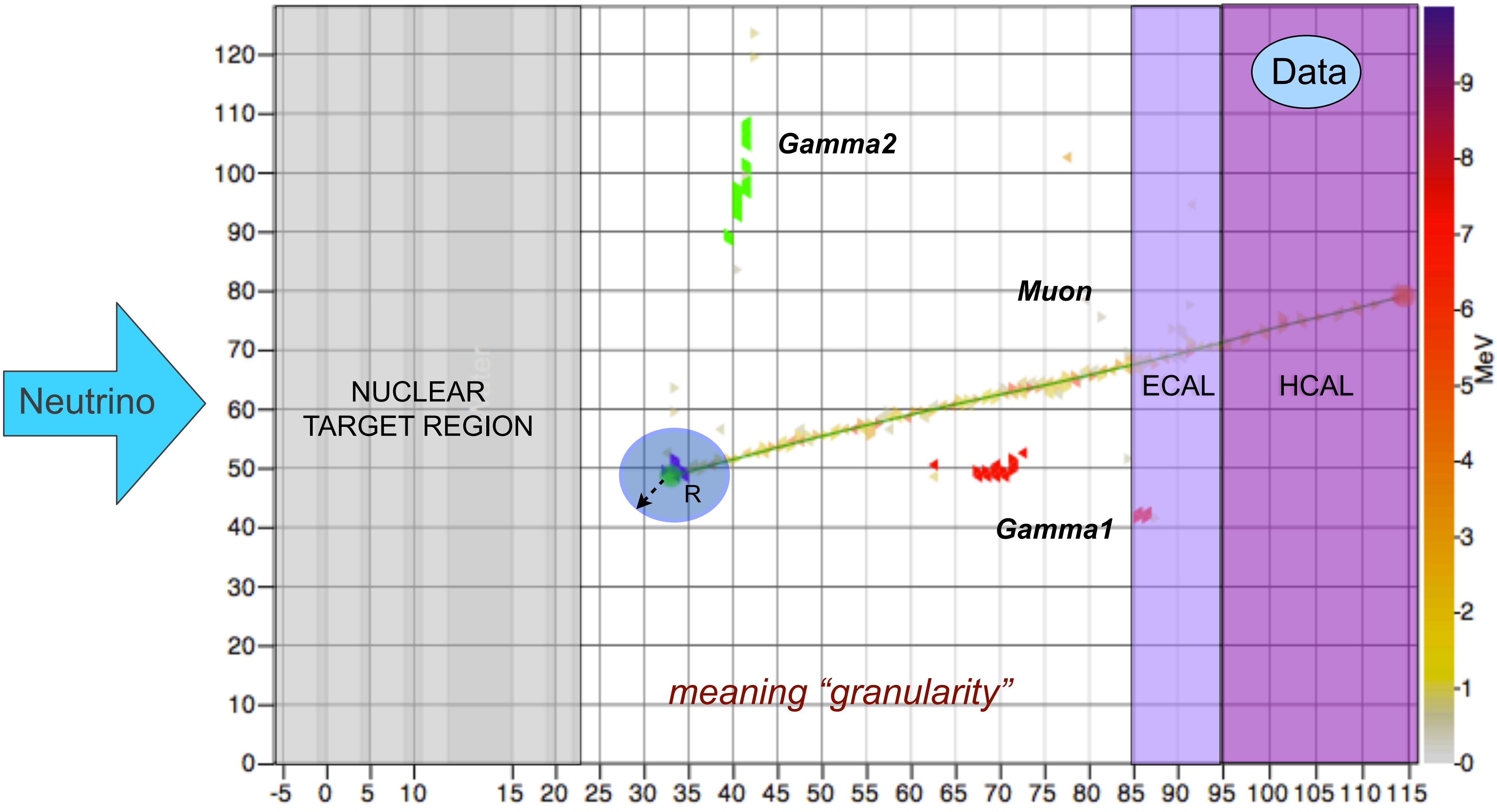




To choose vertex energy cut, the purity must be at least 30%

To reconstruct CCPi0 exclusive events, first we need to reduce all background events, we are using "Vertex Energy"

CCπ^0 reconstruction

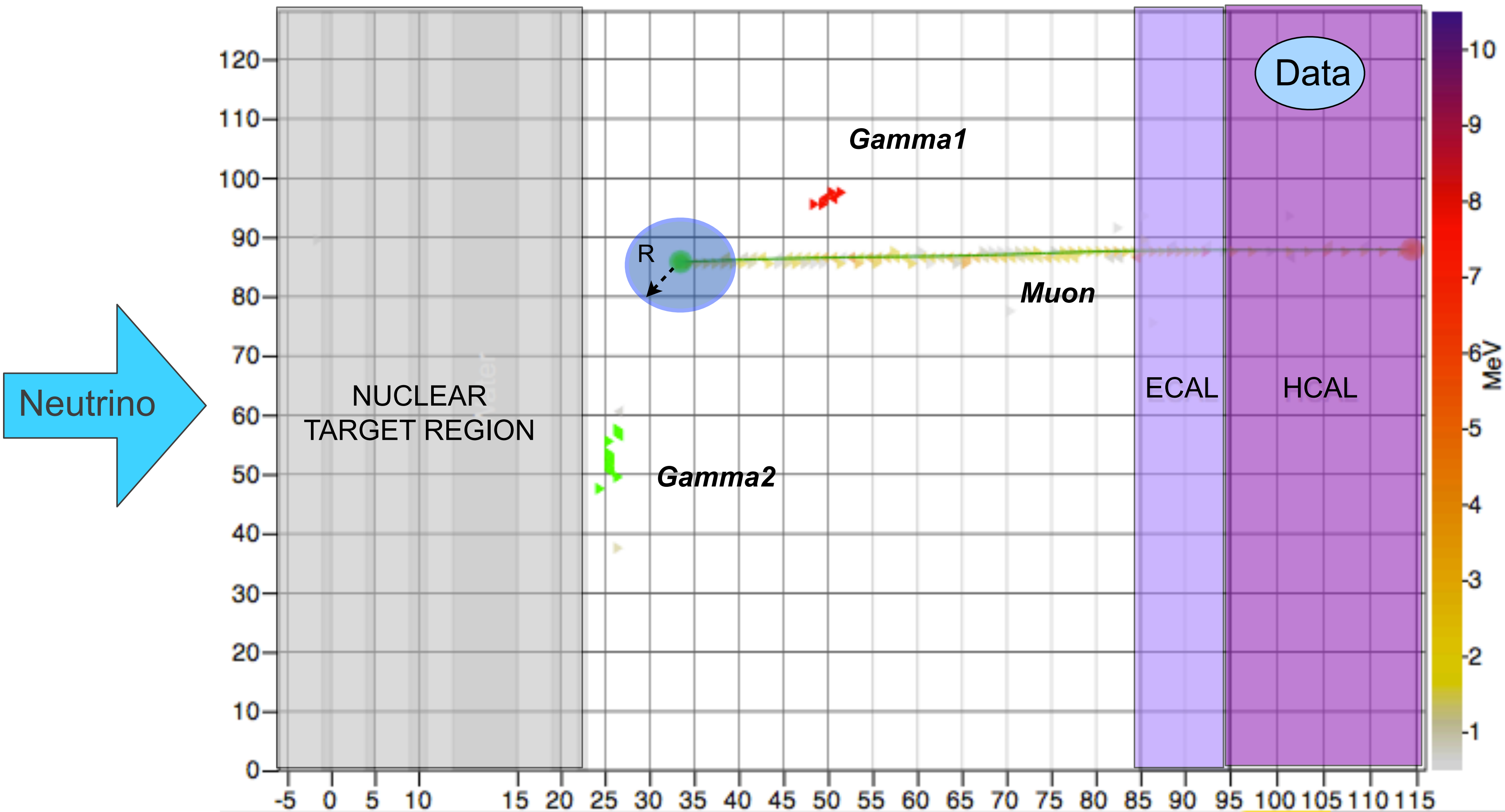


Energy contained inside R = 90*mm*
Vertex Activity = 128.37 MeV

Event ID MV|2671|16|313|1

Reconstructed info:
Mass = 139.47 *MeV/c^2*
Gamma Energy 1 = 132.05 *MeV*
Gamma Energy 2 = 127.40 *MeV*

CCπ^0 reconstruction - exclusive

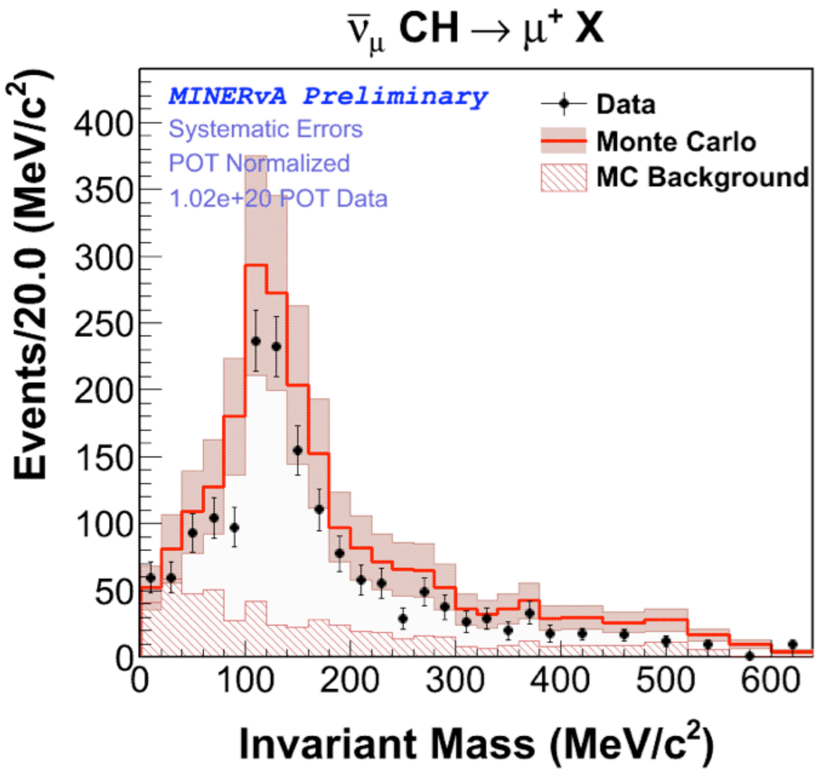


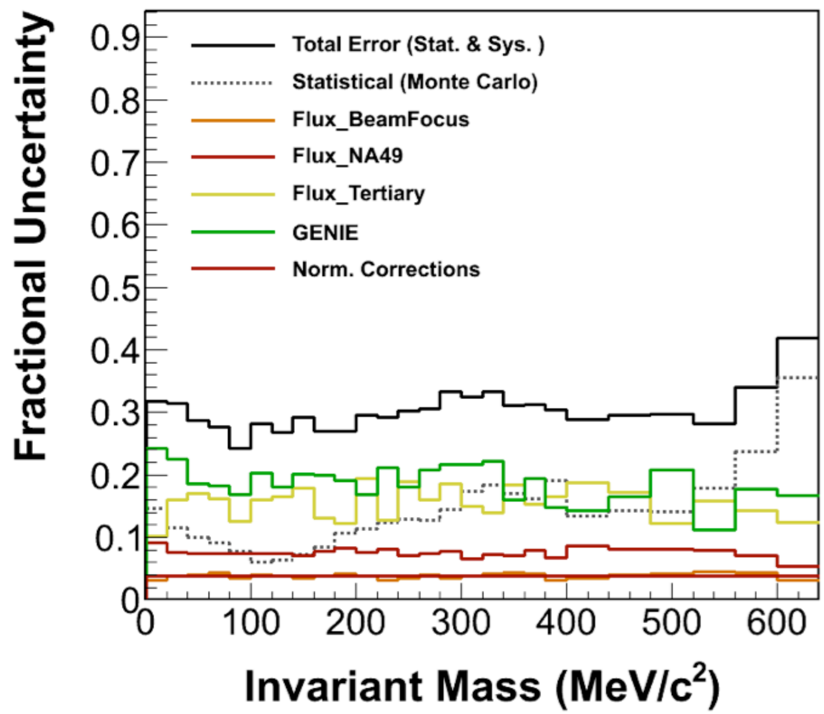
Energy contained inside R = 90*mm*
Vertex Activity = 0 MeV

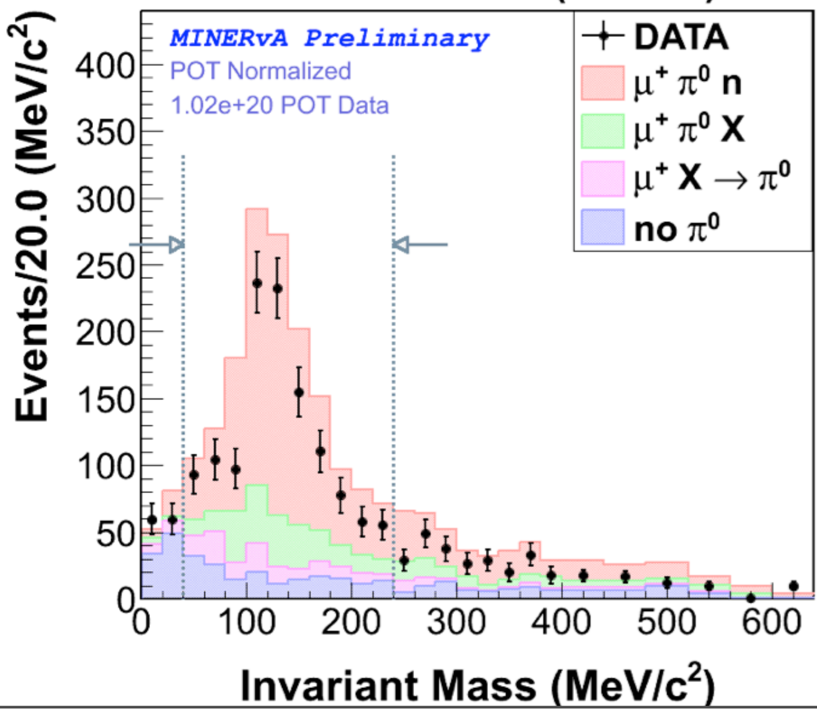
Event ID MV|2703|34|51|1

Reconstructed info:
Mass = 130.88 *MeV/c^2*
Gamma Energy 1 = 164.32 *MeV*
Gamma Energy 2 = 155.12 *MeV*

Invariant Mass after vertex energy cut



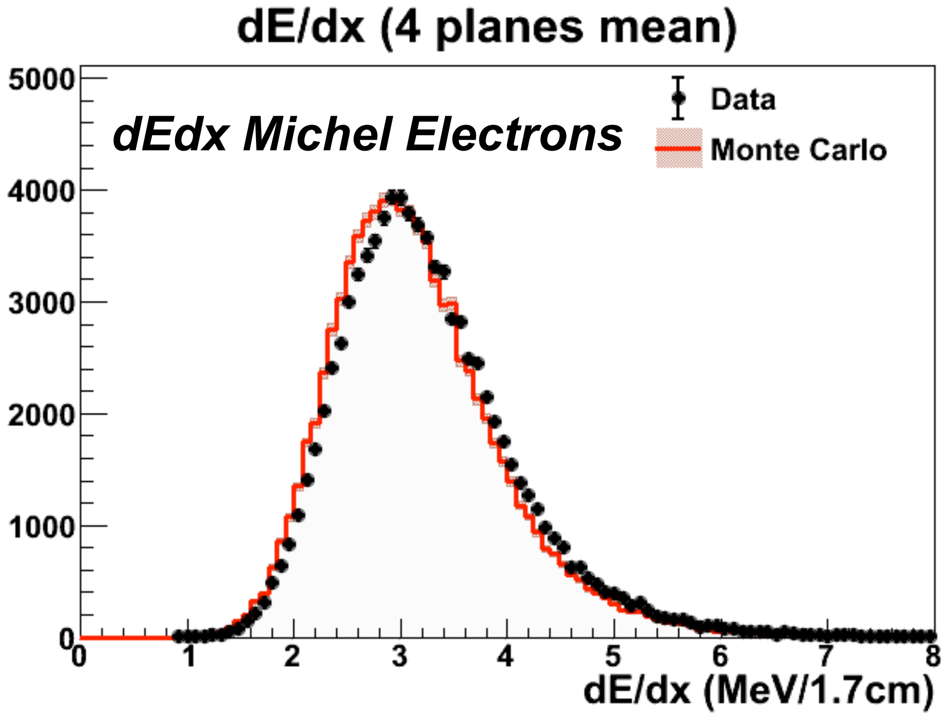




To reconstruct CCPi0 exclusive events, we select events with:

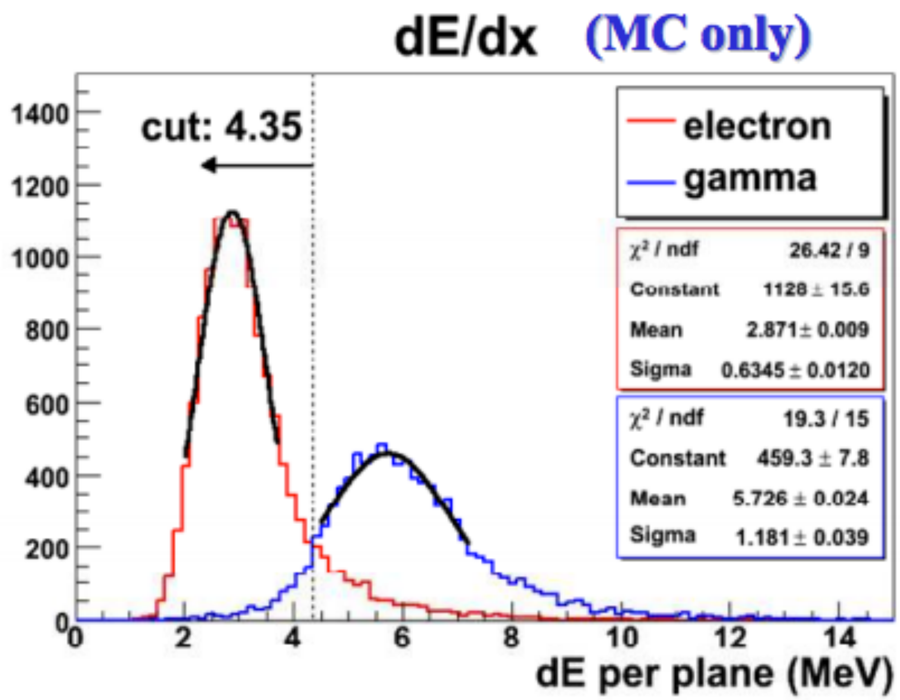
- vertex energy less than 13MeV
- mass between 40 - 240 MeV/c2.

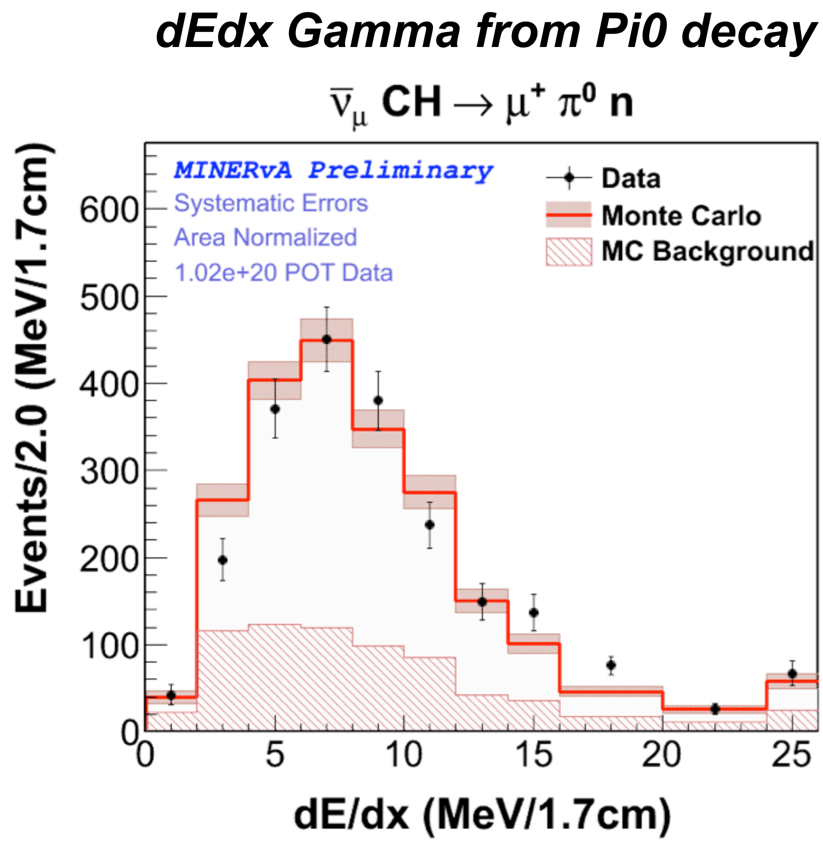
	$CC\pi^0$ exclusive
Purity	(67%)
Efficiency	(7%)



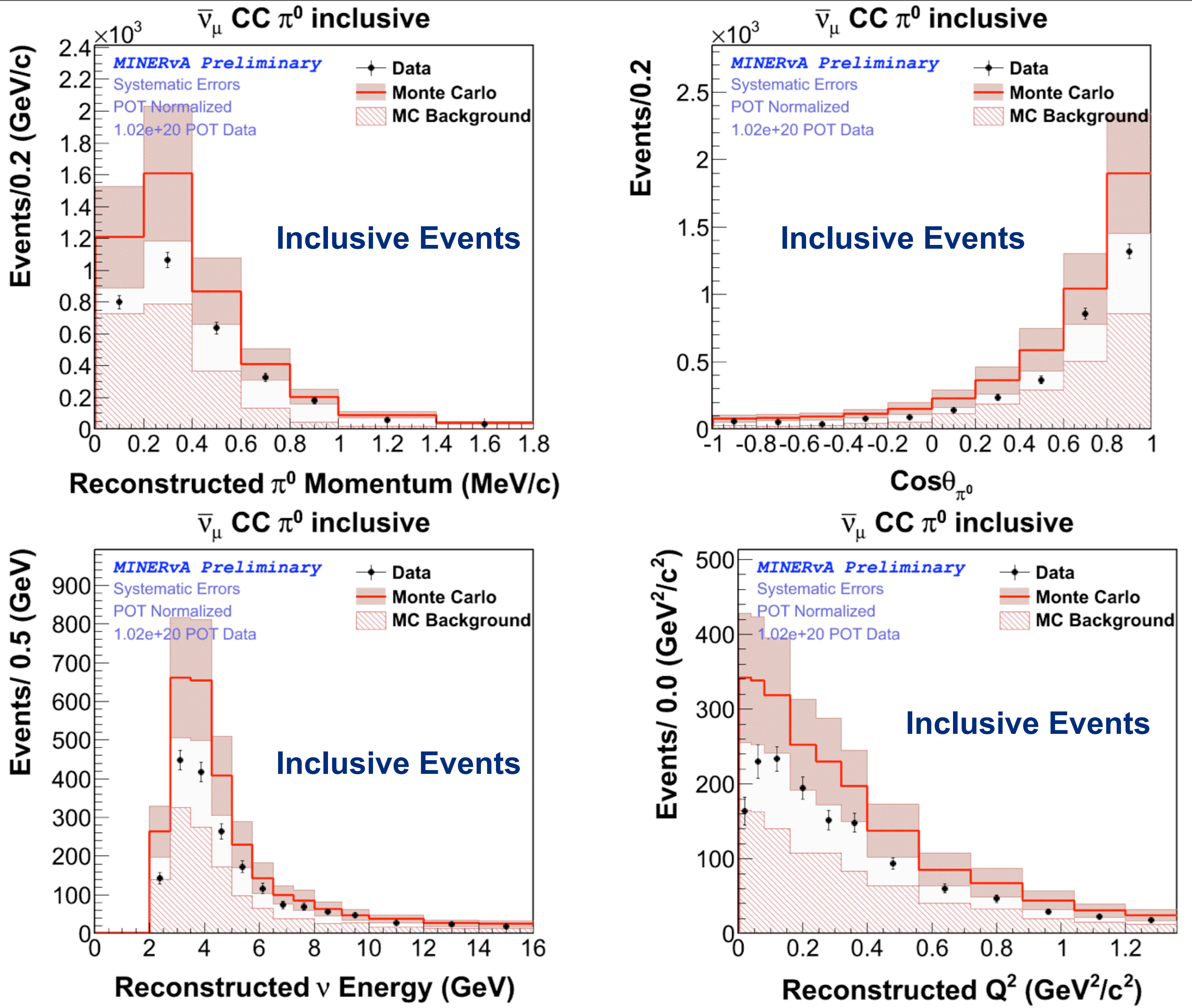
MINERvA detector allow us identify Gammas and Electrons. dEdx tool is good for pid particles on EM showers.

To remove Background, we can look at dEdx to isolate gammas.

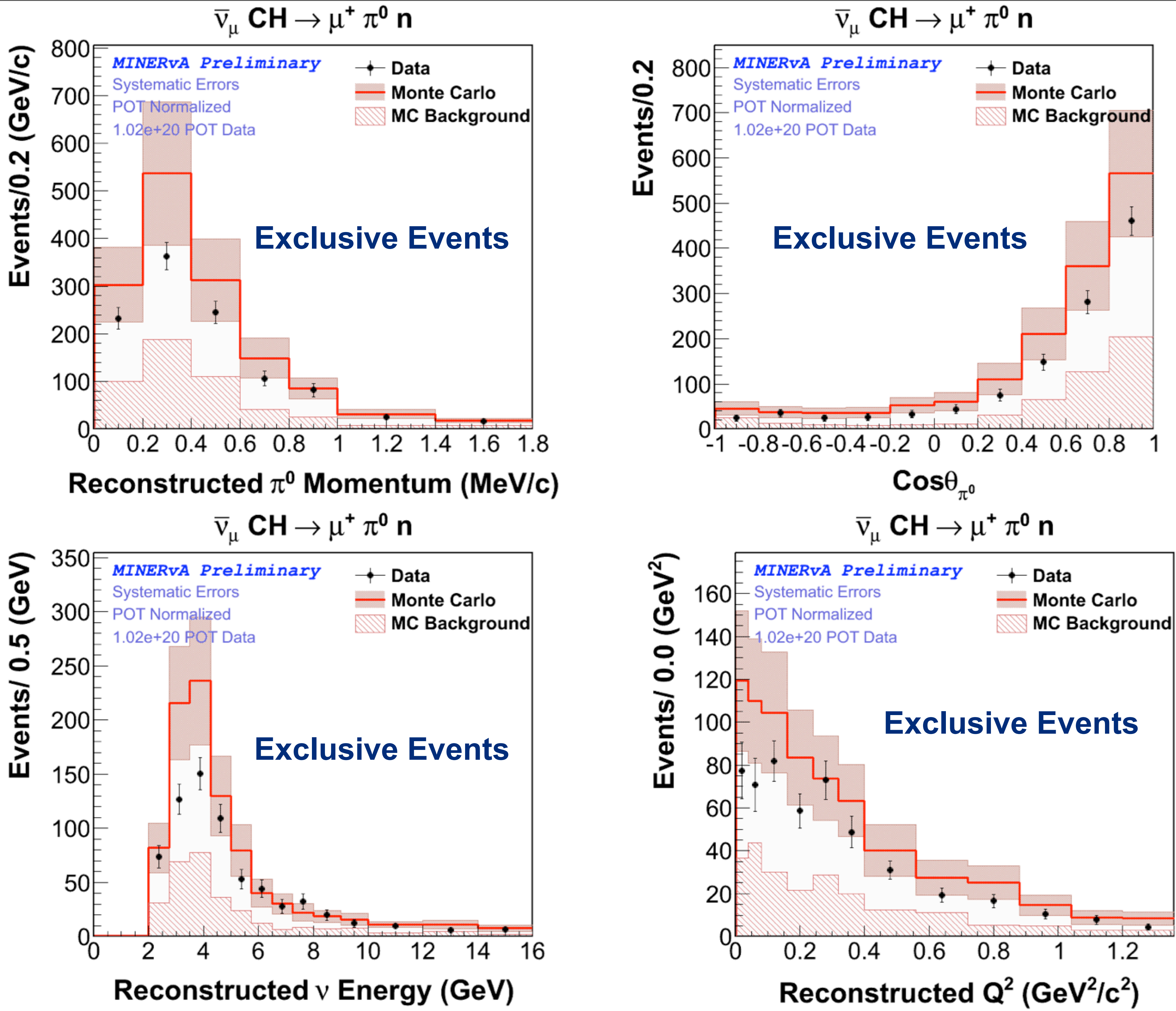




Kinematics Plots



$\bar{\nu}_\mu$ CC π^0 inclusive
MINERvA Preliminary
Systematic Errors
POT Normalized
1.02e+20 POT Data
Data
Monte Carlo
MC Background
Inclusive Events
×10³
Events/0.2 (GeV/c)
Reconstructed π^0 Momentum (MeV/c)
$\bar{\nu}_\mu$ CC π^0 inclusive
MINERvA Preliminary
Systematic Errors
POT Normalized
1.02e+20 POT Data
Data
Monte Carlo
MC Background
Inclusive Events
×10³
Events/0.2
Cosθ_{π^0}
$\bar{\nu}_\mu$ CC π^0 inclusive
MINERvA Preliminary
Systematic Errors
POT Normalized
1.02e+20 POT Data
Data
Monte Carlo
MC Background
Inclusive Events
Events/ 0.5 (GeV)
Reconstructed ν Energy (GeV)
$\bar{\nu}_\mu$ CC π^0 inclusive
MINERvA Preliminary
Systematic Errors
POT Normalized
1.02e+20 POT Data
Data
Monte Carlo
MC Background
Inclusive Events
Events/ 0.0 (GeV²/c²)
Reconstructed Q² (GeV²/c²)

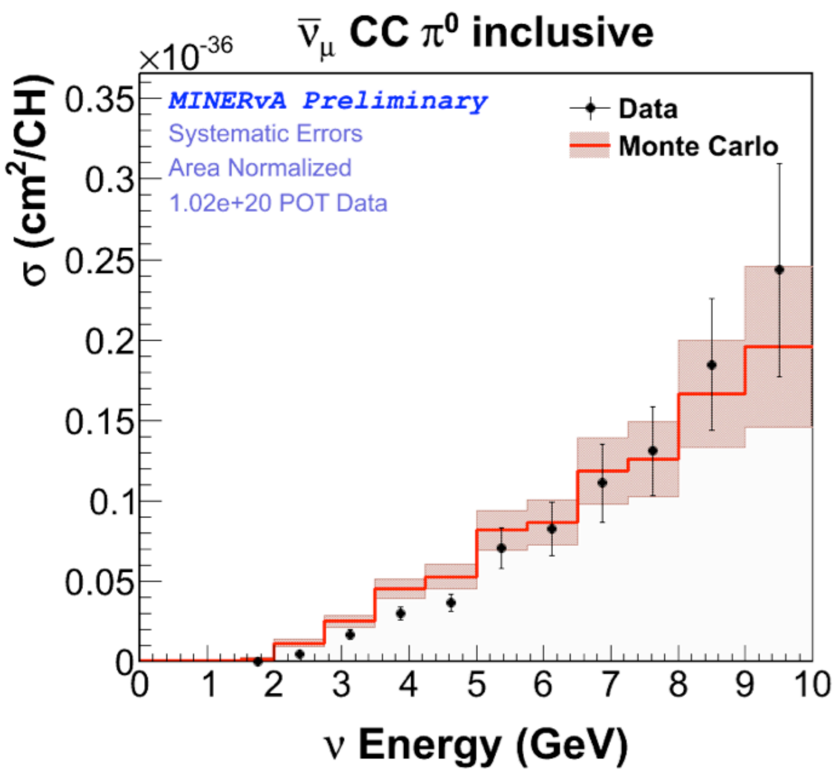

$\bar{\nu}_\mu$ CH $\rightarrow \mu^+ \pi^0$ n
MINERvA Preliminary
Systematic Errors
POT Normalized
1.02e+20 POT Data
Data
Monte Carlo
MC Background
Exclusive Events
Events/0.2 (GeV/c)
Reconstructed π^0 Momentum (MeV/c)
Events/0.2
$\cos\theta_{\pi^0}$
Events/ 0.5 (GeV)
Reconstructed ν Energy (GeV)
Events/ 0.0 (GeV^2)
Reconstructed Q^2 (GeV^2/c^2)

Cross Section

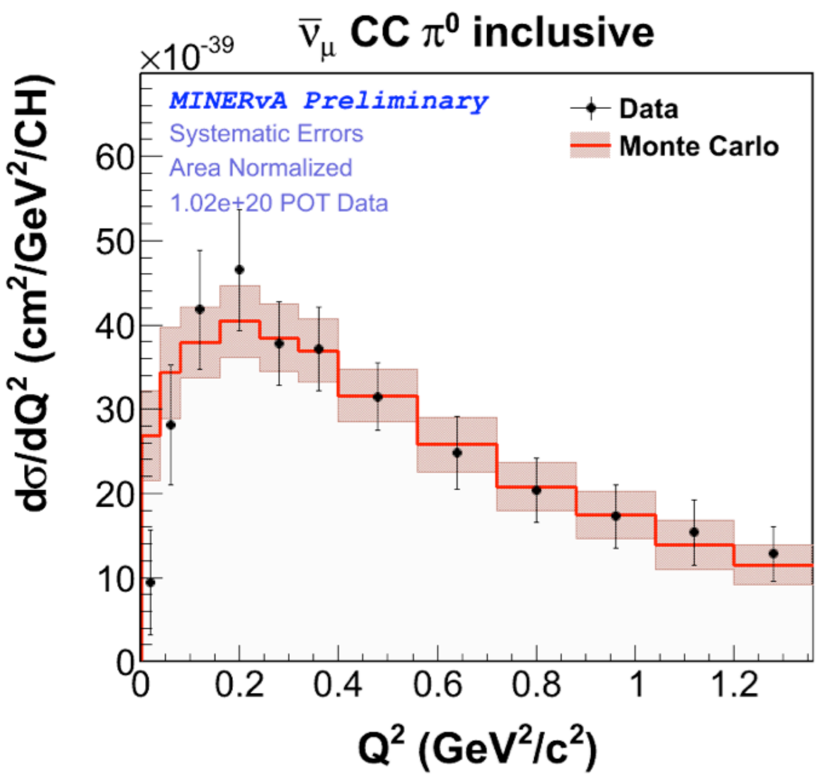
Steps
1.- Background substraction
2.- Unfold (bayesian)
3.- Efficiency correction

$$\left.\frac{\partial\sigma}{\partial x}\right|_i = \frac{\sum_j U_{ij}(N_j - B_j)}{n\Phi_i\epsilon_i\Delta x_i}$$

Inclusive Events

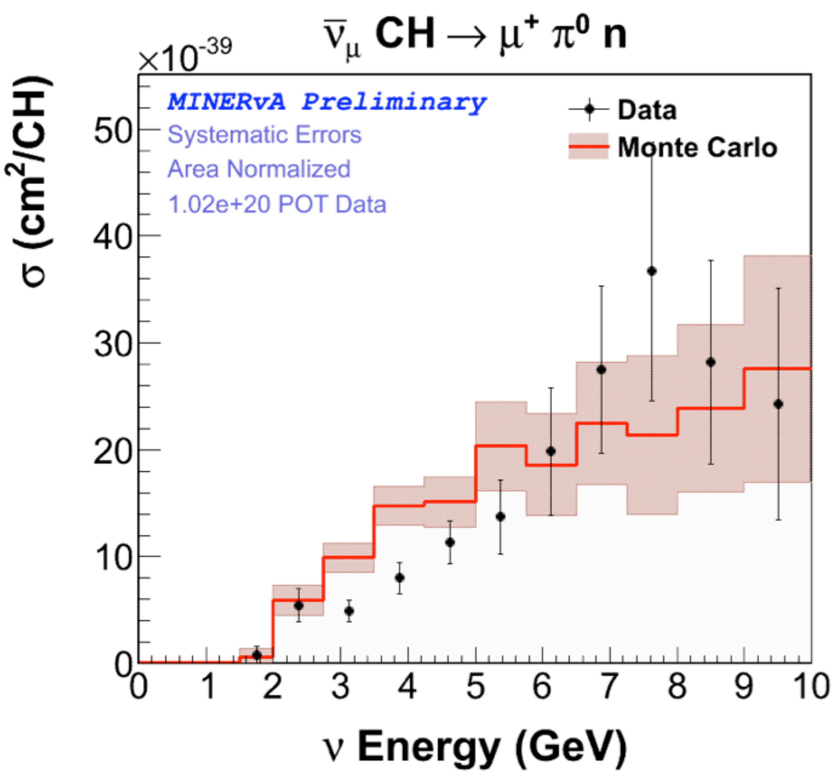


Inclusive Events

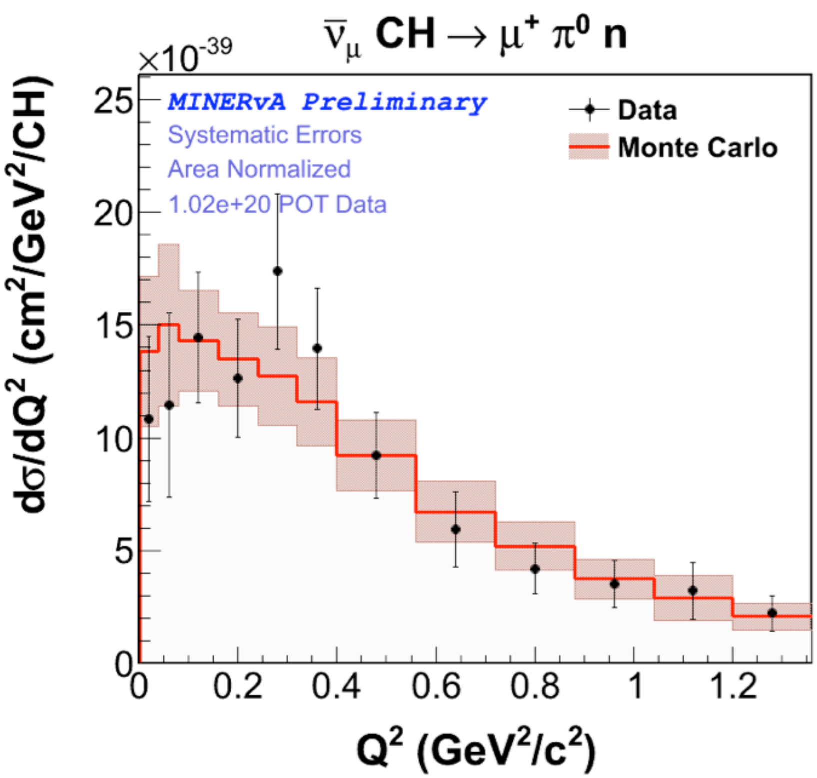


Area normalized!!

Exclusive Events

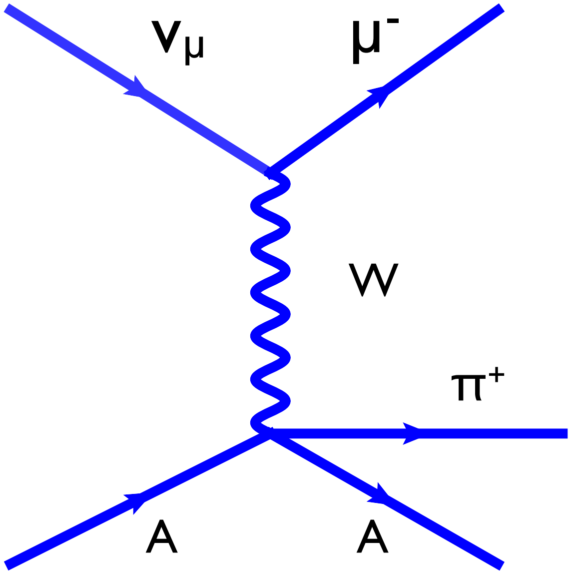


Exclusive Events



Area normalized!!

Charged Current Coherent Pion Production

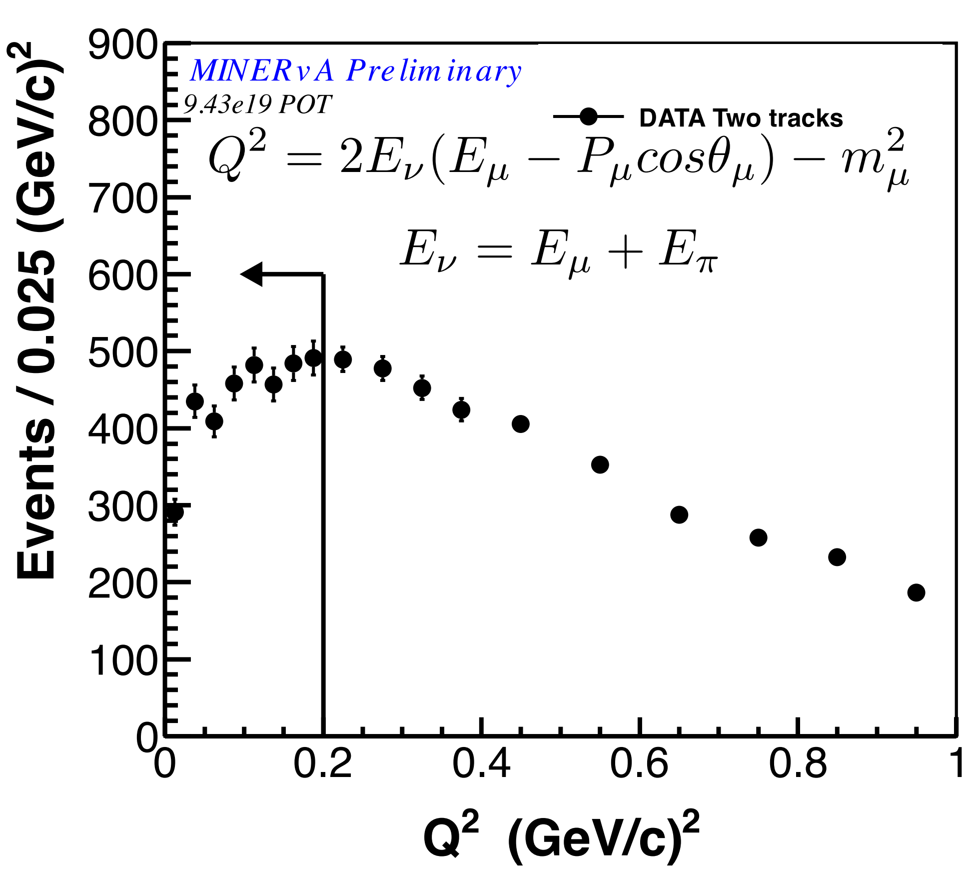


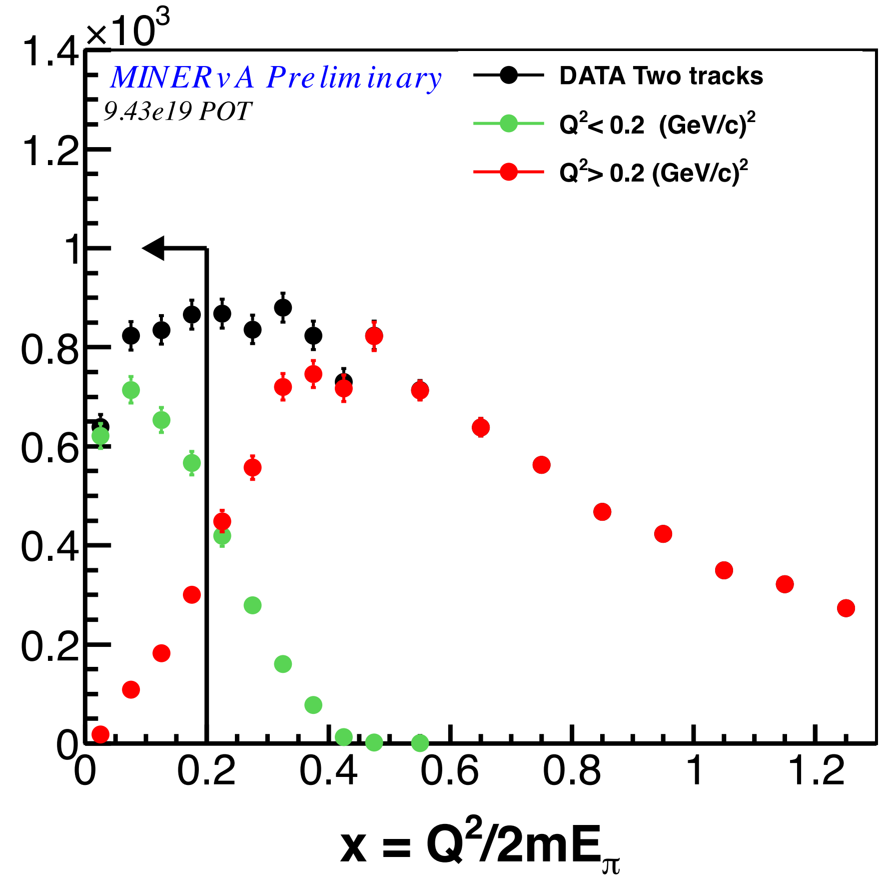
details at Aaron Higuera poster "Charged Current Charged Pion and Charged Current Coherent Pion Production"

- The defining feature of the interaction is that the hadronic final state contains a single pion and a residual nucleus is in its ground state.
- Coherent interactions have a great practical application to neutrino experiments because NC coherent pion production is part of the background to the ν_e appearance measurement.
- The cross sections are low and backgrounds (usually from resonance pion production processes) are large.
- Measurements have been made for CC, however recent measurements could not find evidence at the very lowest energies. NC coherent has only been estimated from the sum of signal plus background.

Towards a Data-Driven Analysis

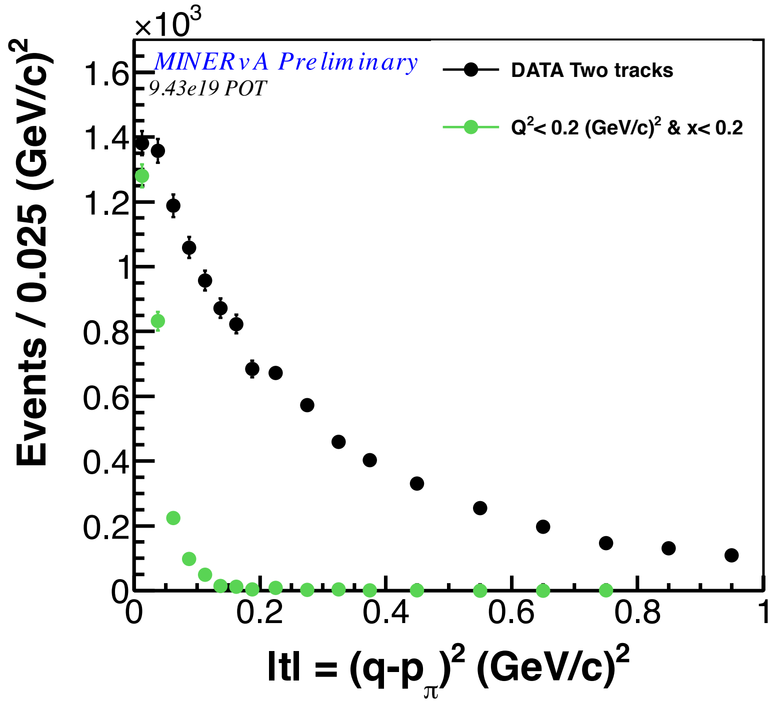
- According to Partially Conserved Axial vector Current models (PCAC) CC coherent pion production must be produced at very low Q^2 ($Q^2 < m^2_\pi$) in order to be in the PCAC regime.
- MINERvA will take that assumption as a start point in its effort to isolate CC coherent pion production. This analysis requests two tracks coming out of a common vertex in the tracker and one of them identified as a muon using MINOS near detector (MINERvA muon spectrometer).
- A $Q^2 < 0.2$ $(GeV/c)^2$cut emphasize small x for coherent pion production, since $<E_\pi>$ for coherent is larger than $<E_\pi>$ for resonances, a $x < 0.2$ cut enriches the coherent sample.



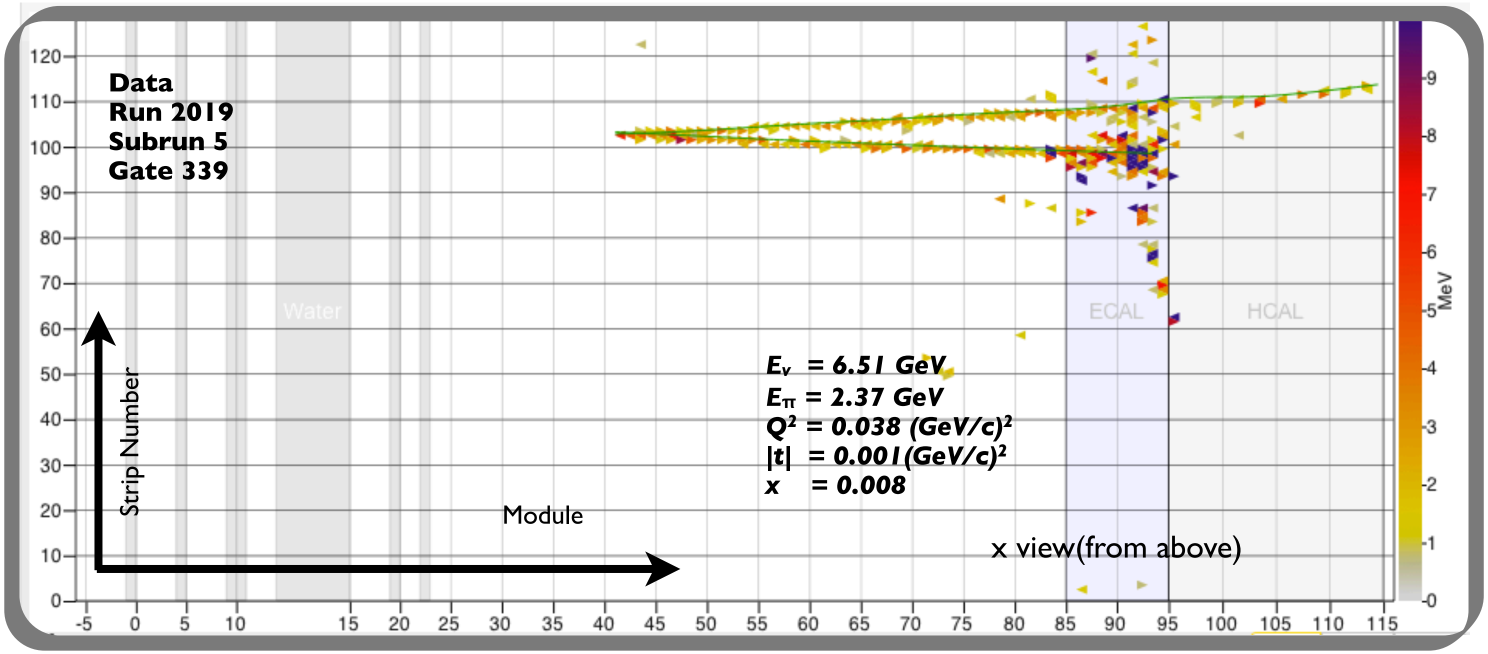


Towards a Data-Driven Analysis

- The 4-momentum transfer to the nucleus |t| = $(q-p_\pi)^2$ must be small by definition.
- By requiring kinematic cuts ($Q^2 < 0.2\ (GeV/c)^2$ and $x < 0.2$) MINERvA is able to isolate CC Coherent candidates.



Charged Current
Coherent Pion Production Candidate



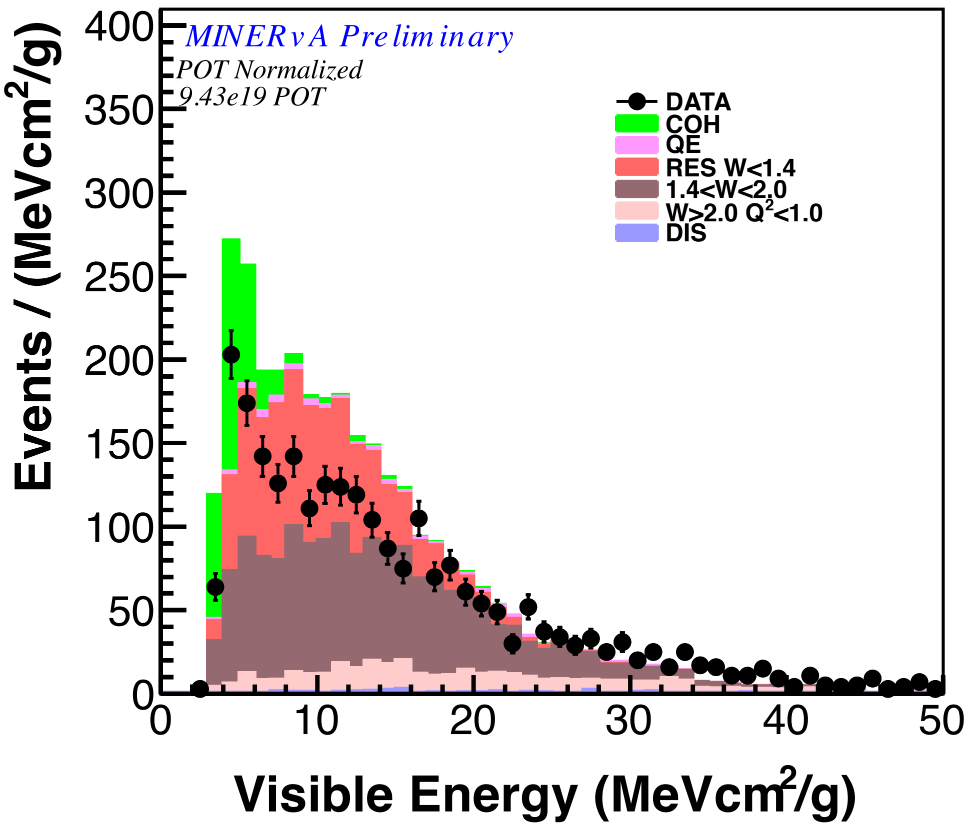
Summary

- MINERvA has the capability to study π^0 production for both neutrino and anti-neutrino and isolate exclusive process using energy around vertex. $NC\pi^0$ production is a large background to neutrino oscillation.
- MINERvA is able to isolate CC Coherent Candidates. With high statistics and good tracking capabilities MINERvA will provide a precision measurement of the coherent pion production cross section of multiple nuclear targets.
- The algorithm to isolate, reconstruct and identify electromagnetic showers works for π^0 identification. Preliminary results are close.

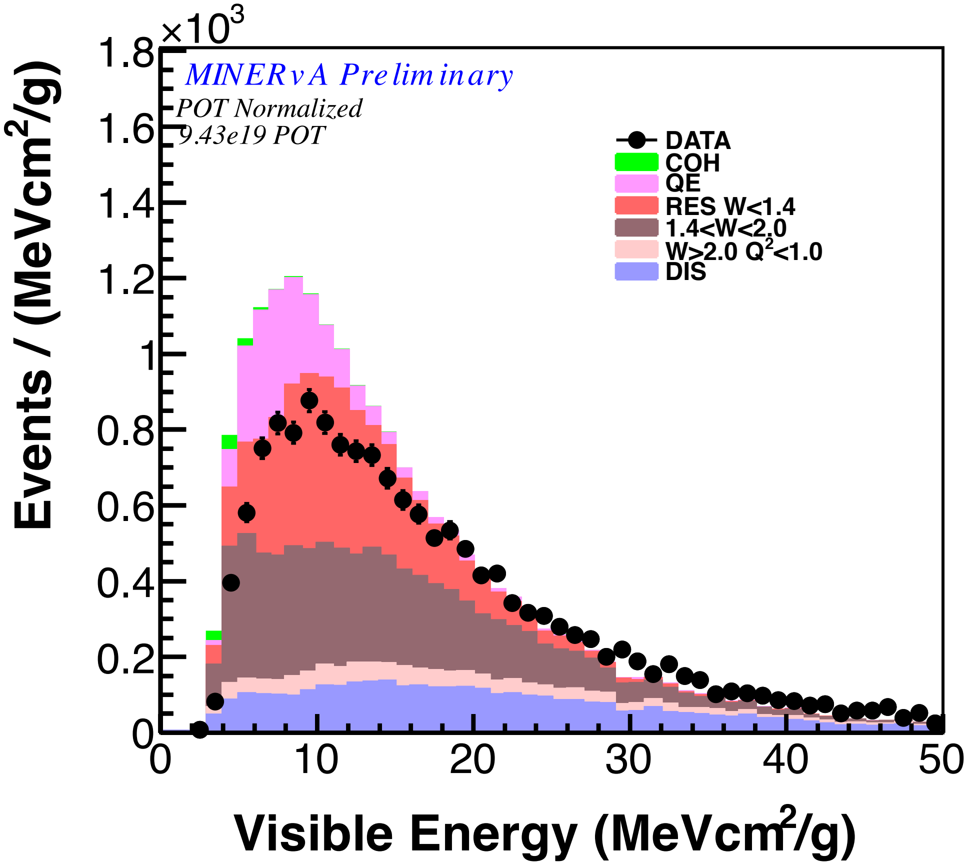
Backup Slides

Energy at the Vertex

$Q^2 < 0.2\ (GeV/c)^2$ & $x < 0.2$



$Q^2 > 0.2\ (GeV/c)^2$ & $x > 0.2$

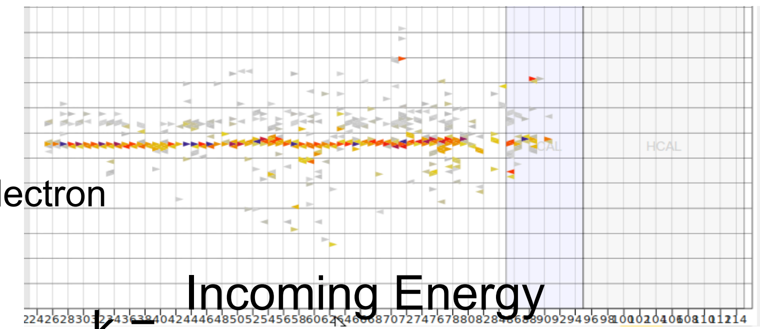


- Since the 4-momentum transfer to the nucleus $|t| = (q-p_\pi)^2$ must be small the energy at the vertex should be consistent with two minimum ionizing particles.

Shower Energy reconstruction

All hits are included to calculate calorimetric constants

electron



$$k = \frac{\text{Incoming Energy}}{\text{Visual Energy}}$$

There are minimum requirements for events when are reconstructed

Calorimeter	# of hits
Electromagnetic	20
Hadronic	25

Number of hits in Calorimeter is Required

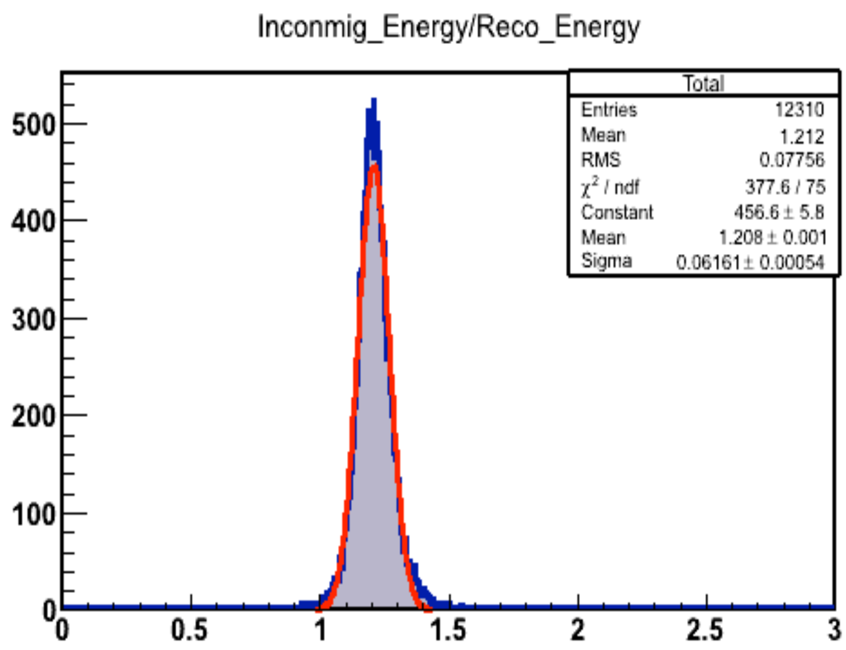
SubDetector	Reconstructed Energy(MeV)
Tracker	41.36
ECal	36.26
HCal	15.63

No well defined for low energy

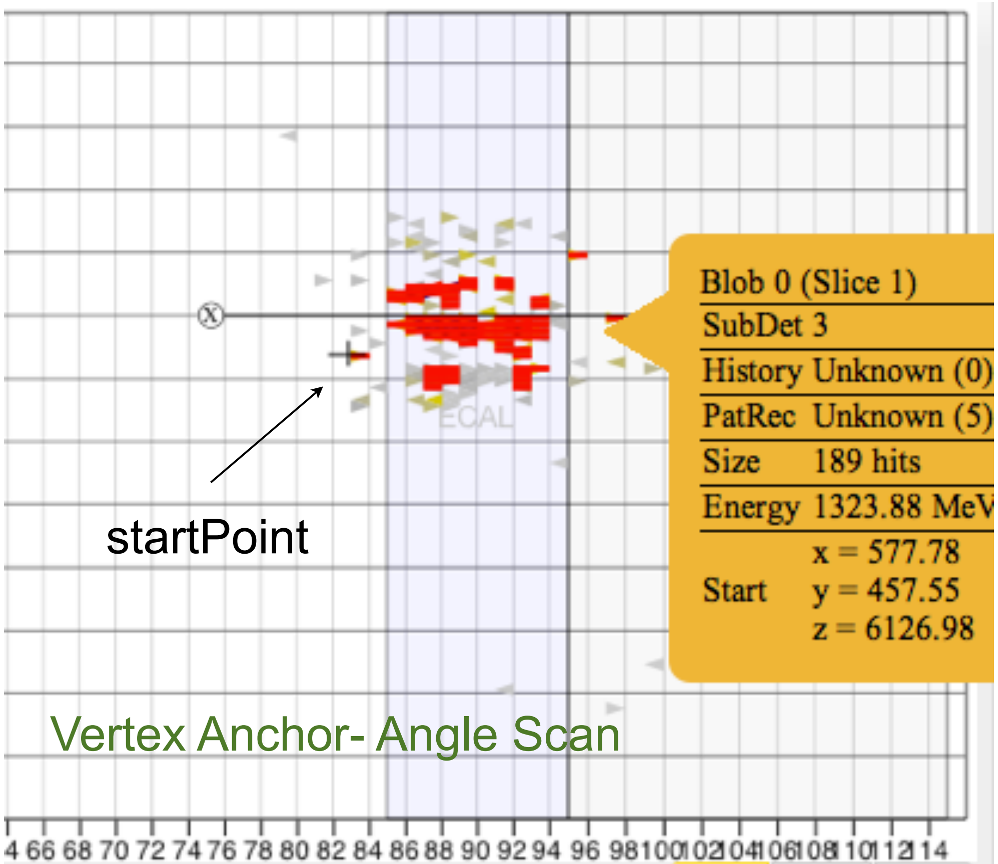
$$E_{True} = \alpha\left(E_{tracker} + k_E E_{ECal} + k_H E_{HCal}\right)$$

Sub-Detector	Constants
α	1.213
K_E	2.274
K_H	10.55

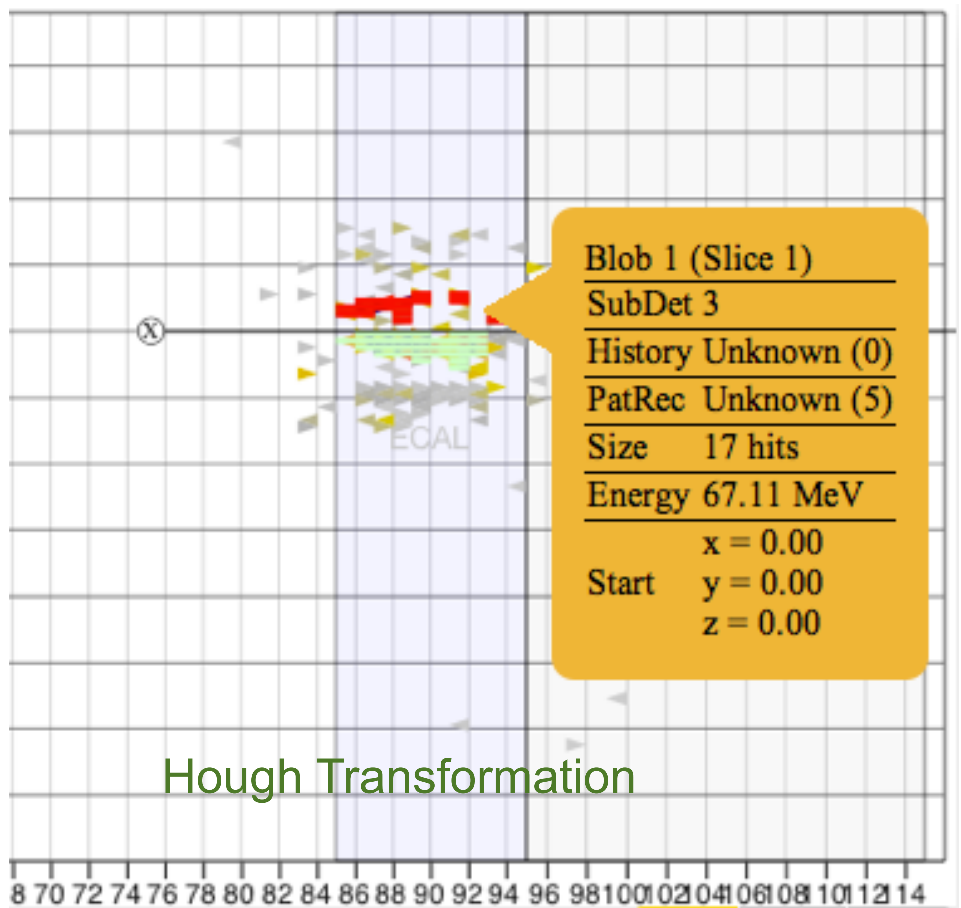
Constant for Tracker



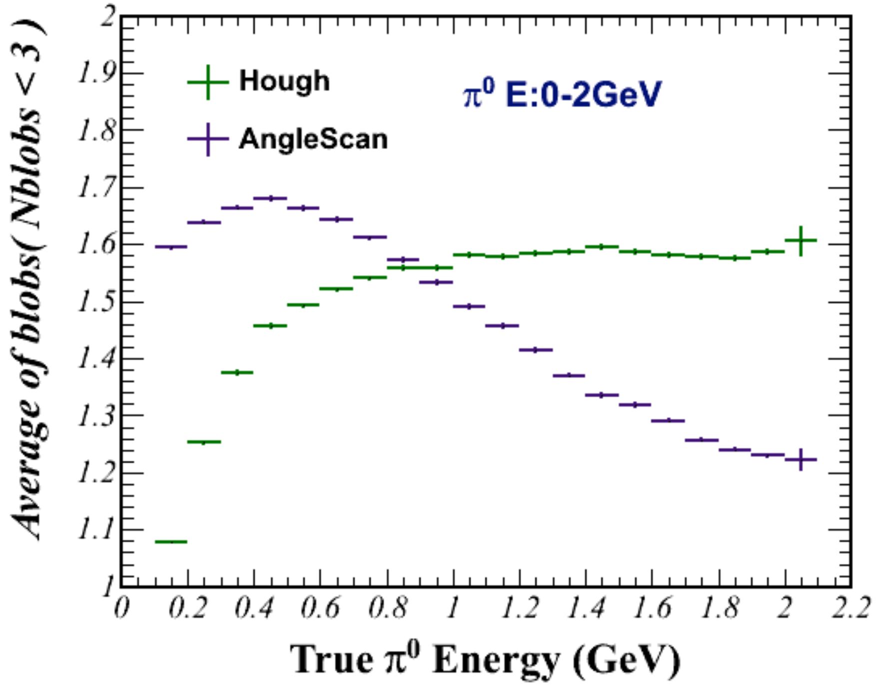
Anchor Angle Scan vs Hough Transform

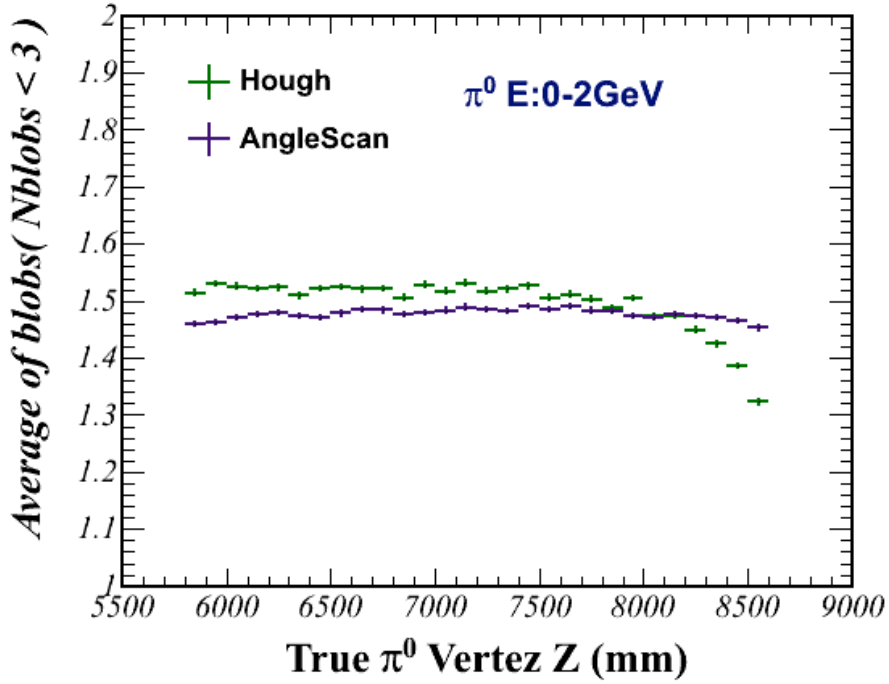


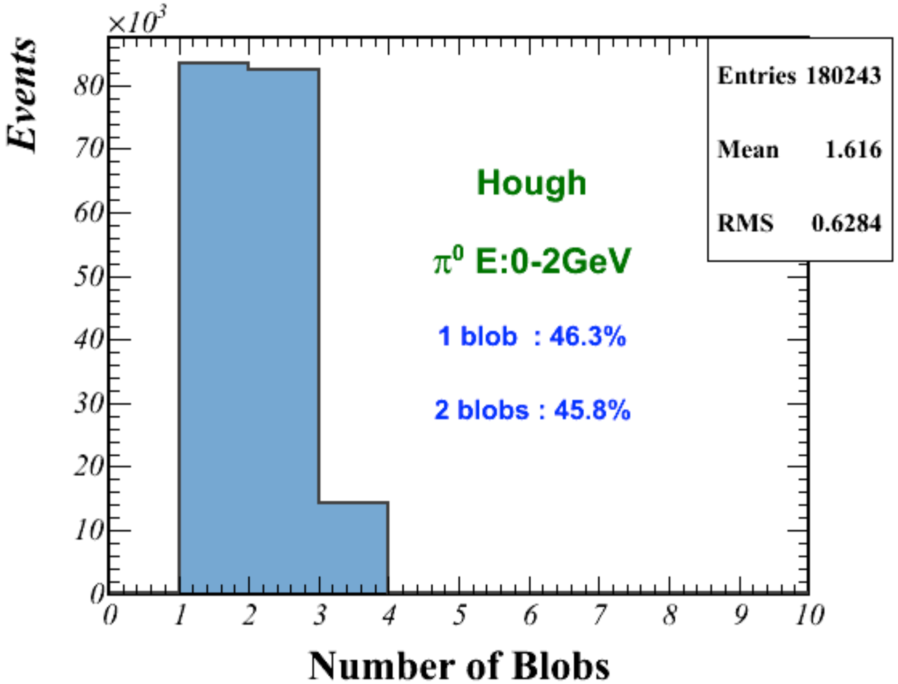
Hough Transform works better when opening angle < 25 degrees

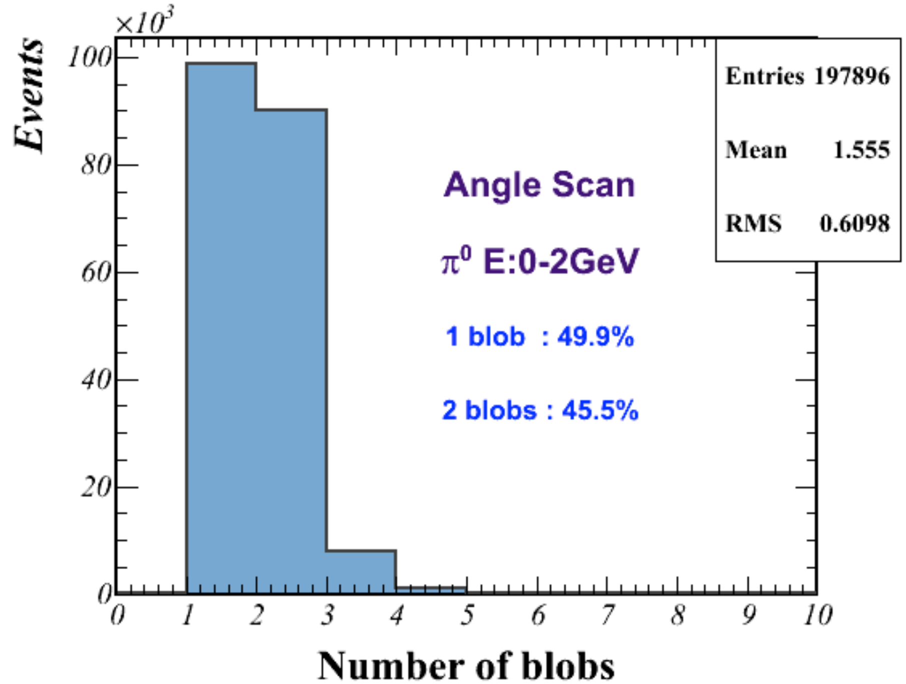


EM Showers on π^0 sample









Important formulas for Pi0 reconstruction

Reconstructed Energy for electromagnetic showers:

$$E_{reco} = \alpha(E_{tracker} + k_{ECal}E_{Ecal} + k_{HCal}E_{HCal})$$

Opening angle:

$$p_{\gamma_1}.p_{\gamma_2} = |p_{\gamma_1}||p_{\gamma_2}|cos\theta_{\gamma\gamma}$$

Invariant mass:

$$m_{\gamma\gamma} = \sqrt{2E_{\gamma_1}E_{\gamma_2}(1-\cos\theta_{\gamma\gamma})}.$$

Pi0 energy:

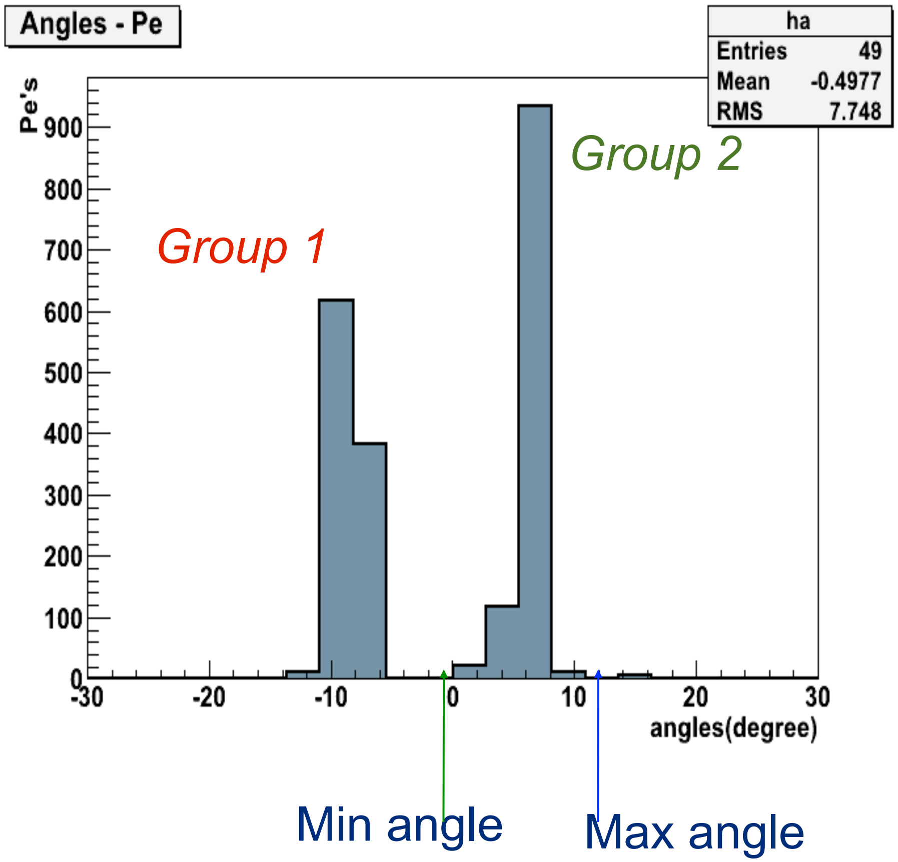
$$E_{\pi} = E_{\gamma 1} + E_{\gamma 2}$$

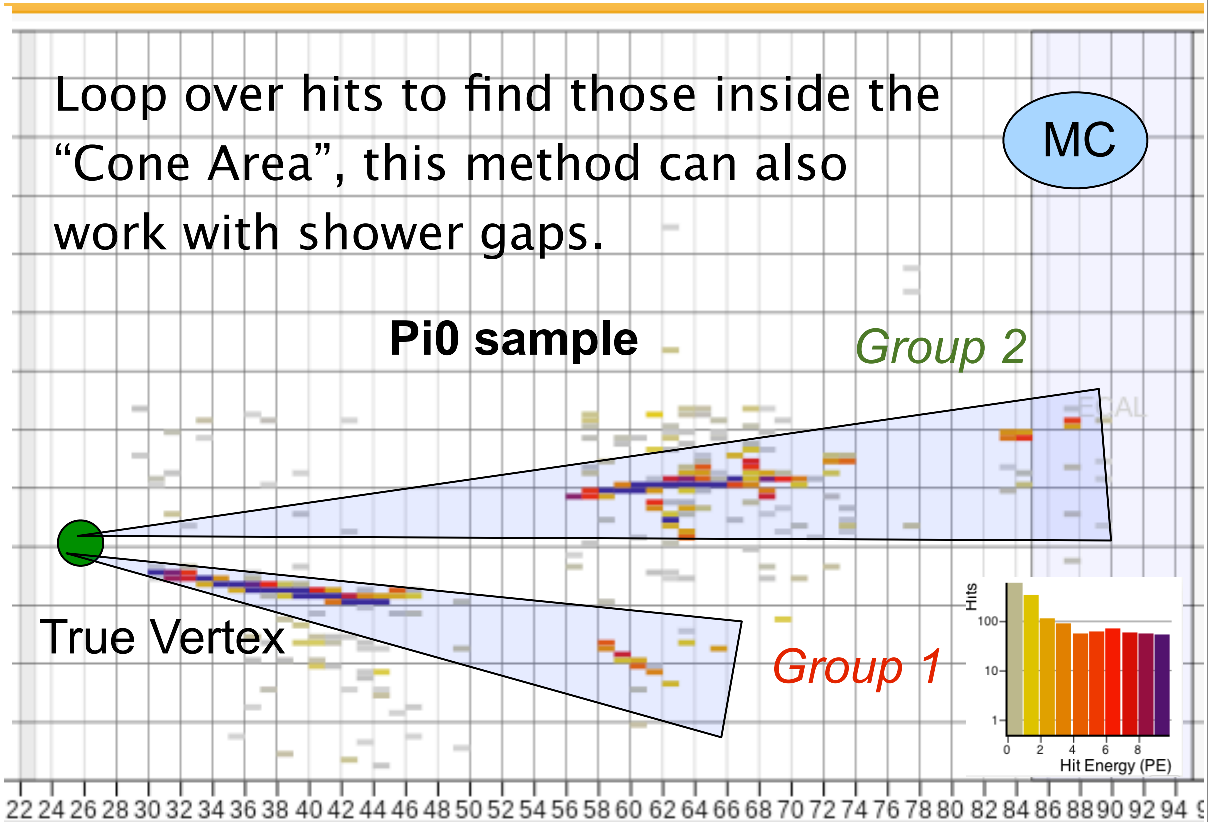
Pi0 momentum:

$$\boldsymbol{p}_{\pi} = \boldsymbol{p}_{\gamma_1}^{\mathrm{REC}} + \boldsymbol{p}_{\gamma_2}^{\mathrm{REC}}$$

Reconstructing Photons for π^0's "Angle Scan"

**PE: photon electron*

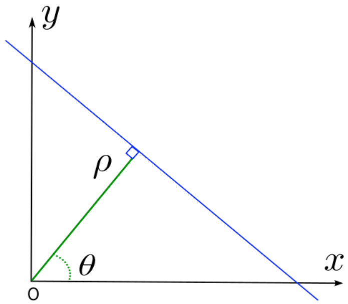




Every group (particle) inside the histogram will have a minimum angle and maximum angle

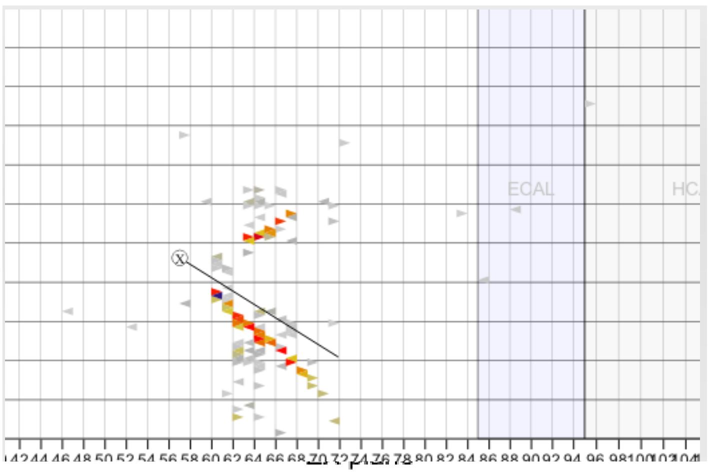
Using vertex like reference point, It fills out a 1D histogram, where every entry is the angle between every hit and the vertex, weighted by its charge. Similar to Hough Transformation with r fixed.

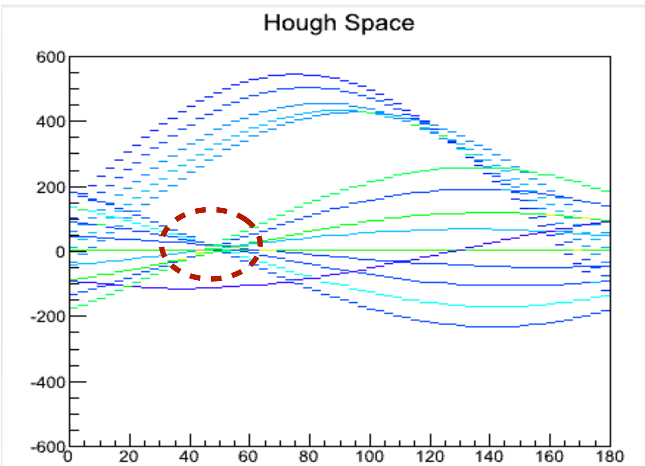
Reconstructing Photons for π^0's "Hough Transform"



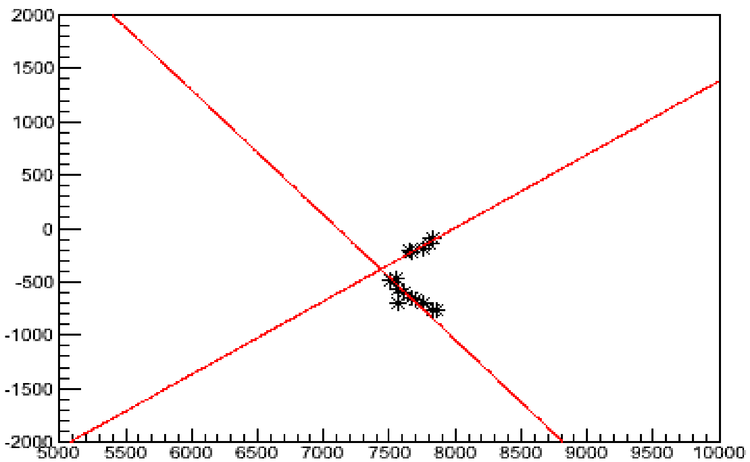
$$x cos\theta + y sin\theta = \rho$$

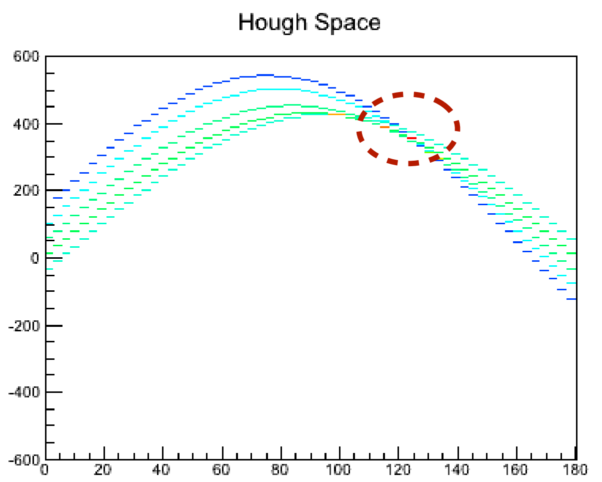
For each point in xy plane we can obtain a sinusoidal line (r,θ) in Hough Space





First loop to remove energetic Blob





Second loop to remove extra Blob

Neutrino Energy Reconstruction on CCπ^0

A CCπ^0 event is the form $\overline{\nu} + p \rightarrow \mu^+ + n + \gamma + \gamma$

Using 4 momentum conservation:

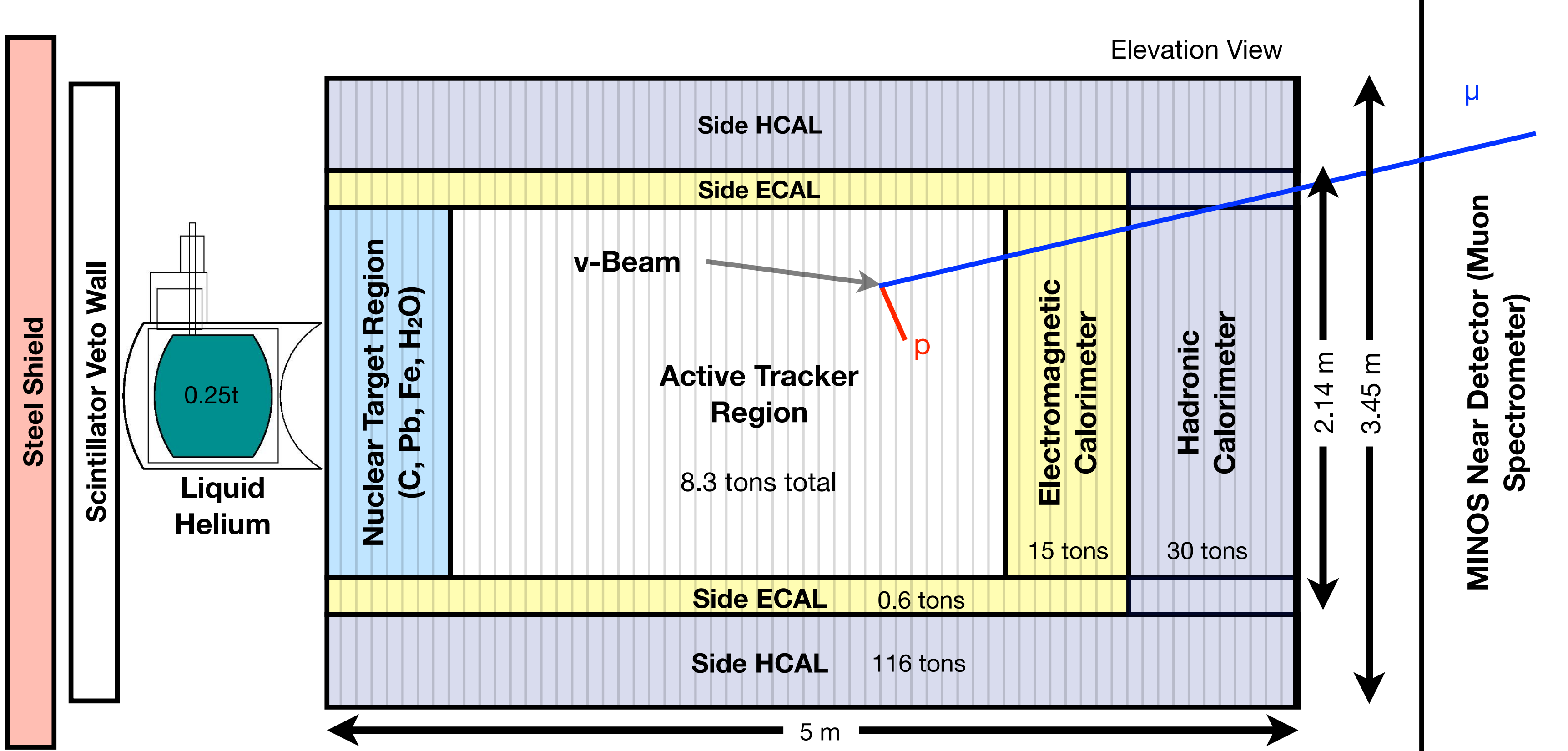
$$(P_{\overline{\nu}} + P_p - P_X)^2 = P_n^2 \quad , P_X \equiv P_\mu + P_{\gamma 1} + P_{\gamma 2}$$

$$E_{\overline{\nu}} = \frac{1}{2} \frac{M_n^2 - M_p^2 - M_X^2 + 2M_p E_X}{M_p - E_X + 2|\overline{p}_X| cos\theta_{\overline{\nu}X}}$$

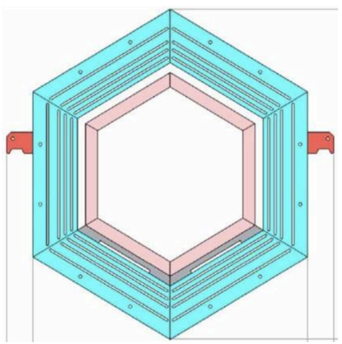
Where, X replaces the typical lepton momentum used to derive the standard QE Neutrino energy formula.

R.H.Nelson, MiniBooNE
arXiv:0909.1238v1

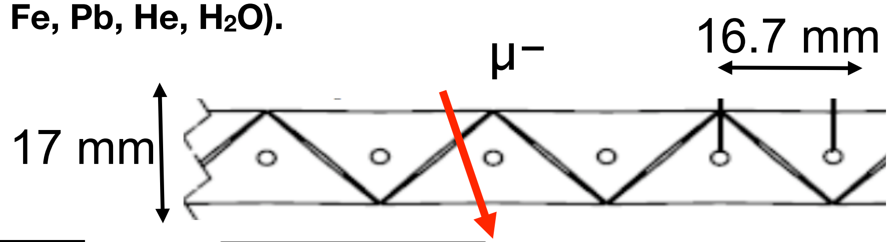
MINERvA Detector



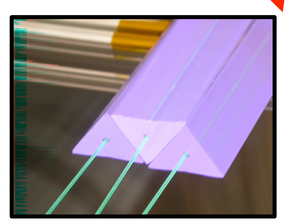
The MINERvA detector is comprised of a stack of MODULES of varying composition, with the MINOS Near Detector acting as a muon spectrometer. It is finely segmented (~32 k channels) with multiple nuclear targets (C, CH, Fe, Pb, He, H_2O).



127 scintillator strips per plane.



Tracker module = 2 planes
ECAL module = 2 planes + 2 (2 mm thick) sheet of lead
HCAL module = 1 plane + 1 (1 inch thick) sheet of steel



Triangular strip to allow charge sharing